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ROLL LAMINATING FIBER OVERLAYS ON LOW-GRADE PONDEROSA PINE LUMBER

by
Lincoln A. Mueller, Roland L. Barger,
Arthur Bourke, and Donald C. Markstrom

PREFACE AND ACKNOWLEDGMENTS

Overlaying low-grade lumber with cellulose or vinyl overlays offers opportunities for producing interior and exterior products with improved appearance, utility, and market value. Recent developments in thermosetting emulsion adhesives and continuous-process roll lamination equipment have generated renewed interest in overlaid lumber products. This report describes the results of pilot tests conducted to investigate the commercial feasibility of roll laminating fiber overlays on low-grade ponderosa pine lumber.

The study included a broad analysis of potential product markets, development of roll laminating techniques, and projection of probable production costs. Additional study objectives were the development of lumber substrate quality requirements, and preliminary evaluation of potential lumber repair techniques.

This research was made possible by a technical assistance grant from the Economic Development Administration, U. S. Department of Commerce. It was conducted cooperatively by the Rocky Mountain Forest and Range Experiment Station and the Duke City Lumber Company, Albuquerque, New Mexico. The support of EDA and the cooperative effort of the Duke City Lumber Company were major factors in the success of the study. The Forest Service's Forest Products Laboratory also provided important technical guidance and consulting assistance during the study. In addition, the Wood Products Laboratory at Carbondale, Illinois, a facility of the North Central Forest Experiment Station, conducted the resawing tests for us. The authors are further indebted to the Rocky Mountain Station's marketing research staff for assistance in analyzing potential markets for overlaid products.

Abstract

Pilot plant tests were conducted with recently developed roll laminating equipment and thermosetting emulsion adhesives. Lumber that met substrate quality requirements was satisfactorily overlaid at speeds up to 180 feet per minute. Costs of overlaying, exclusive of substrate, ranged from $0.04 to $0.05 per square foot of product. A high proportion of Common grade lumber contains defects that cannot be overlaid. A second study phase found that abrasive planing (for surface defects) and urethane foam fillers (for voids) are promising repair techniques. Using selected or repaired lumber, overlaid products can be manufactured within a competitive price range. There is no strong market acceptance for such products at present, however, and aggressive market development will be needed. Commercial feasibility is currently restricted by the need for an effective automated defect repair system, and by lack of assured markets.

Keywords: *Pinus ponderosa,* forest products, lumber finishing.

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Rocky Mountain Forest and Range Experiment Station[1]

ECONOMIC DEVELOPMENT ADMINISTRATION
TECHNICAL ASSISTANCE PROJECT
U.S. DEPARTMENT OF COMMERCE

[1] *Central headquarters is maintained at Fort Collins, in cooperation with Colorado State University. At the time research was conducted Mueller, Barger, and Markstrom were wood technologists, with Mueller and Markstrom at Fort Collins, and Barger at Flagstaff in cooperation with Northern Arizona University. Mueller is now retired, and Barger is with the U. S. Forest Service Regional Office at Missoula, Montana. Bourke was resident development engineer in charge of the pilot plant at Albuquerque, New Mexico.*

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INTRODUCTION

Lower Common grades of softwood lumber have historically been marginal products, for which demand and price are poor. The problem is particularly acute in southwestern ponderosa pine, where approximately two-thirds of the lumber produced falls in grades 3 Common and lower. For the entire Inland Region, including the Southwest, approximately half of the lumber produced is grade 3 Common or lower. Due to increasing utilization of younger residual and second-growth stands, the proportion of low Common lumber is likely to remain high. The purpose of this study was to investigate, on a pilot-plant scale, the technical and economic feasibility of upgrading low-quality ponderosa pine lumber by applying fiber overlays.

The study ultimately included two phases, one concerned with roll-laminating fiber overlays on acceptable lumber substrates, and a second concerned with methods of repairing defects that are unacceptable for overlaying in low-grade lumber. Phase I included a market analysis for overlaid products, an analysis of quality requirements for lumber substrates, and development of roll-laminating techniques. Results indicated that effective lumber repair methods were needed to make the process effective. Phase II was initiated to evaluate potential repair methods, including chemical and wood-plug patching, abrasive planing, and selective cut-up.

Basic research to identify the most promising overlay techniques and materials has been underway since 1932. These earlier efforts, some of which have been reported previously (Barger and Fleischer 1964, Fleischer and Heebink 1964, Hall 1954, Heebink 1961), showed that the overlay process had considerable potential for improving the surface characteristics of plywood and lumber. When most of this basic work was completed, however, overlaying was essentially restricted to batch process methods. The batch process imposed severe production limitations upon the overlaying of lumber, and limited the configuration of overlay and size of material that could be handled. Consequently, overlaid products received little attention until recent developments in adhesives and roll-laminating equipment made it possible to apply overlays to lumber continuously, and to wrap the overlay around the edges of the board. The roll laminator used in our study was patterned after a prototype developed in the laboratories of National Starch and Chemical Company, and was built by Eric Riebling Company, New York.[2]

Although not all the technical problems in overlaying were entirely resolved by earlier work, those familiar with the development agreed that the process was ready for pilot testing. The pilot plant was located at the Duke City Lumber Company plant in Albuquerque, New Mexico, under a cooperative agreement. The plant processes lumber received from several company mills in Arizona and New Mexico, which provided ready access to a full range of lumber grades.

PHASE I:

OVERLAID PRODUCT MARKET ANALYSIS AND MANUFACTURE

The Market Analysis

A preliminary market analysis was needed to provide a basis for selecting the most promising overlaid products for pilot-plant tests. With the assistance of a consulting firm that specializes in analyzing markets for construction products, a market screening study was conducted to:

1. Identify overlaid products that offered greatest potential.
2. Identify major competitive products.
3. Determine performance requirements and price levels for such products.
4. Estimate market size and characteristics.

[2] *Trade and company names are used for the benefit of the reader, and do not imply endorsement or preferential treatment by the U. S. Department of Agriculture.*

Product Screening and Market Investigation

The consultant, with Forest Service and industry representatives, selected 7 out of 20 potential overlaid lumber products for study: siding, fascia, shelving, molding and trim, door jambs, paneling, and stadium seats. These products held promise of being economically competitive, could meet performance requirements using a low-grade substrate material, and could capitalize on the advantages offered by an overlaid surface. Preliminary market investigations indicated that three of the seven—siding, shelving, and molding and trim—offered the greatest market potential. Major study efforts were therefore concentrated on evaluating the market potential for these three products.

Market information was obtained largely through personal interviews with representatives of relatively large builders and retail lumber dealers. A total of 179 interviews were obtained in three study areas—Chicago, Los Angeles, and Dallas-Fort Worth.

In brief, the study indicated that market opportunities may exist for a siding product capable of meeting specified performance requirements at a competitive price. Overlaid lumber siding offers sound-absorbing qualities superior to both hardboard and metal siding products and provides an excellent paint base for either on-the-job finishing, or prepriming and/or finishing. Hardboard appears to be the major competitor in the painted siding market.

Molding and trim markets are attractive, and offer significant opportunities for overlaid paintable products. A large proportion of the softwood molding and trim now sold is finger-jointed, and is either prefinished by printing or overlaying, or is painted on the job site. Grain-printed and vinyl-overlaid moldings are already widely accepted and used, and have conditioned the market to accept a paintable overlay. Builders expressed a willingness to buy and try paintable overlaid molding and trim, believing that the product would offer superior surface appearance and performance.

The market potential for overlaid shelving is less assured, primarily because alternative materials are numerous and shelving is not a particularly discriminating use. Lumber continues to dominate the shelving market, however, indicating a potential market for overlaid standard lumber widths. Because overlaid shelving can offer advantages in ease of finishing (or prefinishing), appearance, performance, and maintainability, major markets might be developed for commercial shelving and fixtures.

For all of the product markets studied, competitive products are numerous and relative technical advantages among these alternative products are often obscured by price considerations. Producers of overlaid products should therefore emphasize such inherent advantages of overlays as superior appearance, finish durability, performance, and ease of maintenance. The market analysis underscores the need for aggressive test marketing and pilot installations as an effective means of overcoming the unfamiliarity and apprehension associated with new products.

Other conclusions of general interest from the market analysis were:

1. The concept of overlaid lumber products is generally acceptable, and even attractive, to many potential users if the products offer performance or price advantages over present products.
2. The color of the overlay was found to be important to the trade, even if the product is to be painted after installation. White or light-colored overlays have greater sales appeal, and are more compatible with a full range of finish colors. Priming is considered desirable over naturally dark overlay materials such as vulcanized fiber.
3. Primed and unfinished sidings presently have greater builder acceptance than prefinished products, because they require less care in handling and installation and can be finished in any color desired. Builders reacted favorably to the good paint base offered by overlays.
4. Markets for lumber siding have declined severely in the past decade, with major competitors being hardboard and aluminum. Overlaid siding can offer some of the advantages of these materials—good finishing base, appearance, and maintainability—while providing the ease of installation, strength, and insulating qualities of a solid wood product.

Limitations and Scope

The market investigation was a broad screening study to identify products and markets offering greatest promise. The conclusions are consequently subject to certain limitations. Only lower Common grades of ponderosa pine lumber were considered as substrates, except for molding and trim products. All samples used in the marketing study were overlaid with vulcanized fiber, a blue-gray product, without benefit of pre-priming. Lighter colored overlays or a primed overlay would be expected to receive a more enthusiastic response for most uses. The study was also limited to three major

market areas—Chicago, Dallas-Fort Worth, and Los Angeles—and was largely restricted to building products suitable for distribution through retail lumber dealers. The conclusions reached do not necessarily apply to products made with better quality substrates, to smaller markets or markets in other regions of the country, or to products designed for remanufacturing uses.

The study also considered only products (1) for which overlaying was known to be technically feasible with currently available overlays, adhesives, and techniques, and (2) which could be marketed in sufficient volume to absorb the production of a number of mills. While this broad approach to utilizing large volumes of low-grade lumber may not appear immediately promising, there is a strong possibility that individual firms can develop attractive localized or regional markets for specific products, capitalizing on their established sales organization and clientele.

Selection of Overlays and Adhesives

Lumber Overlays

Overlays for lumber must have some capacity to shrink and swell with dimensional changes in the substrate. Potential lumber overlays include vulcanized fiber, parchments, and acrylic and/or phenolic reinforced papers.

Five-mil vulcanized fiber has been used most extensively in lumber overlay investigations, and was used in all pilot production runs to establish overlaying costs and standard operating procedures. Because considerable performance information is available for 5-mil vulcanized fiber, it was also used as a standard against which performance of other overlays was judged.

Ten-mil vulcanized fiber was used in limited tests to evaluate the effectiveness of heavier overlays in covering defects. The overlay exhibited superior bridging and hiding effectiveness, but because of its stiffness and springback tendency, it could not be successfully wrapped with presently available adhesives. The heavier overlay may afford some advantages where wrap is not essential and the product can justify the more expensive overlay.

Parchment overlays ranging from 1½ to 5 mils (including bleached-unbleached and filled-unfilled variations) were also evaluated. The 1½-mil parchment was difficult to handle due to high hygroscopicity and low wet strength. Parchments from 2½ to 5 mils thick performed satisfactorily. Compared to 5-mil vulcanized fiber, the heavier parchments afford some advantages in cost and adaptability to roll laminating. The durability of finishes on parchment is subject to question, however, and resistance to substrate defect stresses is low. Parchments also allow greater showthrough of defects and stains on the substrate, which could create some objectionable market reaction.

A variety of other overlays ranging from 4 to 20 mils were found to perform less favorably than vulcanized fiber or parchment. Brief trial runs were also made with printed vinyls, which roll laminated satisfactorily. Vinyls are suitable for interior use only, however, and therefore have limited application.

Roll-laminating Adhesives

The roll-laminating process depends on the use of thermosetting adhesives with specific operating characteristics. Cross-linking polyvinyl acetate adhesives were found to perform most satisfactorily. Several formulas were tested, with no single formula having a clearcut superiority over others. Difficulty was experienced in operating with any of the available adhesive formulations at in-plant temperatures below 45°F. and above 105°F. The ultimate selection of an adhesive formula for a particular roll-laminating operation depends on the equipment and overlay material to be used.

Selection of Lumber Substrate

Much early study effort was required to define the types and extent of defect allowable in overlay stock selected from Common lumber grades. Overlays of the type being investigated cannot successfully span voids of any consequence, and will not perform adequately over rough grain and skip. The number and severity of such defects increases gradually as lumber grade decreases.

Development of Roll-laminating Grade

Major objectives of lumber evaluation work were to determine the proportion of overlayable lumber obtainable from each commercial grade, and to establish realistic criteria for an overlayable lumber grade. Approximately 100,000

board feet of lower Common grade lumber was examined in detail and regraded for roll laminating trial runs. Defects in each board were recorded in numerical code on a portable punch-card system. Recorded information included defect types, number, severity, and—to some extent—location in the board. Later observations of performance of the board as a substrate could then be keyed back to the type or severity of defect involved.

Through trial and error, testing, and observation of substrate performance in repeated laminator runs, allowable limits of defect in overlay stock were progressively better defined. These limits have been incorporated into an "overlayable lumber grade" (table 1).

Table 1.--Specifications for overlayable lumber grade[1]

Defect	Allowable limits	Not allowable
Knots	All tight, smooth knots Firm, smooth, encased knots	Loose, decayed, split, fractured, or rough encased knots
Knotholes	1/4 inch or less	All others
Manufacturing defects	Chipped grain Raised grain Slight torn grain (1/32" max.)	Loosened or separated grain Skip Handling damage (dog marks, strap crush, etc.)
Decay	Firm, without voids	All others
Holes, insect, etc.	1/4 inch or less	All others
Checks	Surface checks	All others
Pitch and bark pockets	Smooth, without voids	All others
Compression wood	None allowed	--
Shake	None allowed	--
Pith	None allowed	--
Splits	Short splits, end	All others
Wane	Equivalent to eased edge	All others
Warp:		
Bow	Very light[2]	All others
Crook	Light[2]	All others
Cup	Very light[2]	All others
Twist	Very light[2]	All others
Moisture content	10 percent average, with variation not to exceed ± 2 percent	All others

[1] Summary description of grade: Allowed--All soild and smooth defects regardless of size; light rough or torn grain if limited in depth and area. Not allowed--Voids, severe splits, checks, skips, and warp.

[2] As defined by Western Wood Products Association (WWPA) standard grading specifications.

Recovery from Common Grades

Varying quantities of lumber in all Common grades may meet roll-laminating grade specifications, but the proportion generally declines as the lumber grade drops. The lower grades of lumber allow more defects that are of severe consequence in roll laminating. For defects such as unsound knots and knotholes, however, differences between grades are largely in defect size rather than frequency of occurrence, and affect about the same proportion of boards in grade 3 as grade 4.

To obtain a more conclusive estimate of the volume of lumber suitable for roll laminating, lumber representative of grades 3, 4, and 5 Common was inspected and regraded (table 2). The sample lumber was selected and graded at three widely separated mills, to minimize effects of defect peculiar to a mill or geographic area.

Table 2.--Recovery of overlayable grade lumber from Common lumber at three southwestern mills

Common lumber grade	Acceptable overlay stock	Unacceptable	
		Repairable[1]	Nonrepairable[2]
		Percent	
3	24	67	9
4	8	59	33
5	0	14	86

[1]Defects that could be repaired with plugs, synthetic fillers, or similar techniques.

[2]Defects of type, size, or number that exceed practical limits of repair except by cut-up.

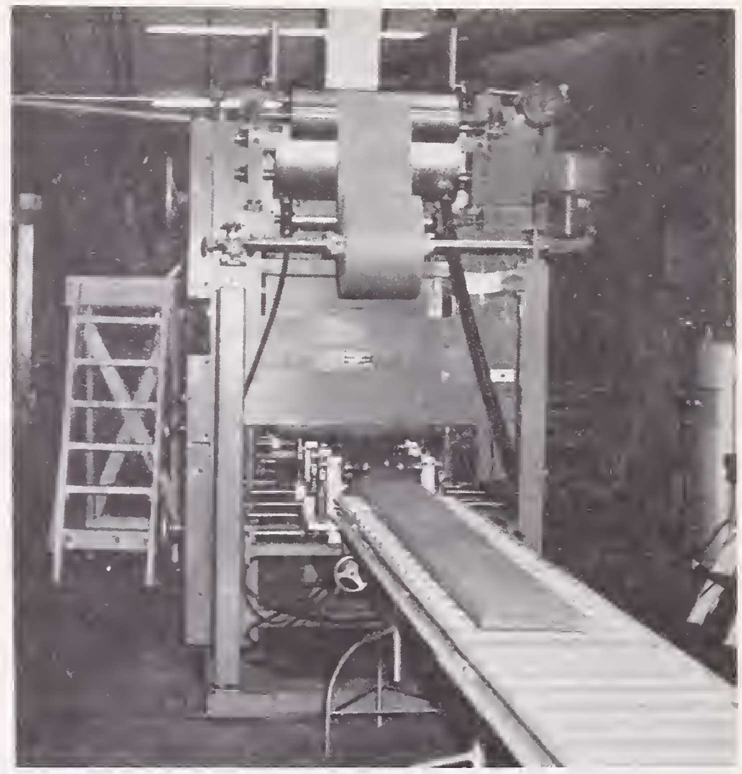


Figure 1.--The roll laminator was developed to continuously laminate fiber overlays to lumber substrates.

Overlaid Product Manufacture

Roll-laminating Equipment

The roll laminator (fig. 1) obtained for the study applies adhesive-coated overlay materials, heated to a precise tack point, to lumber as it

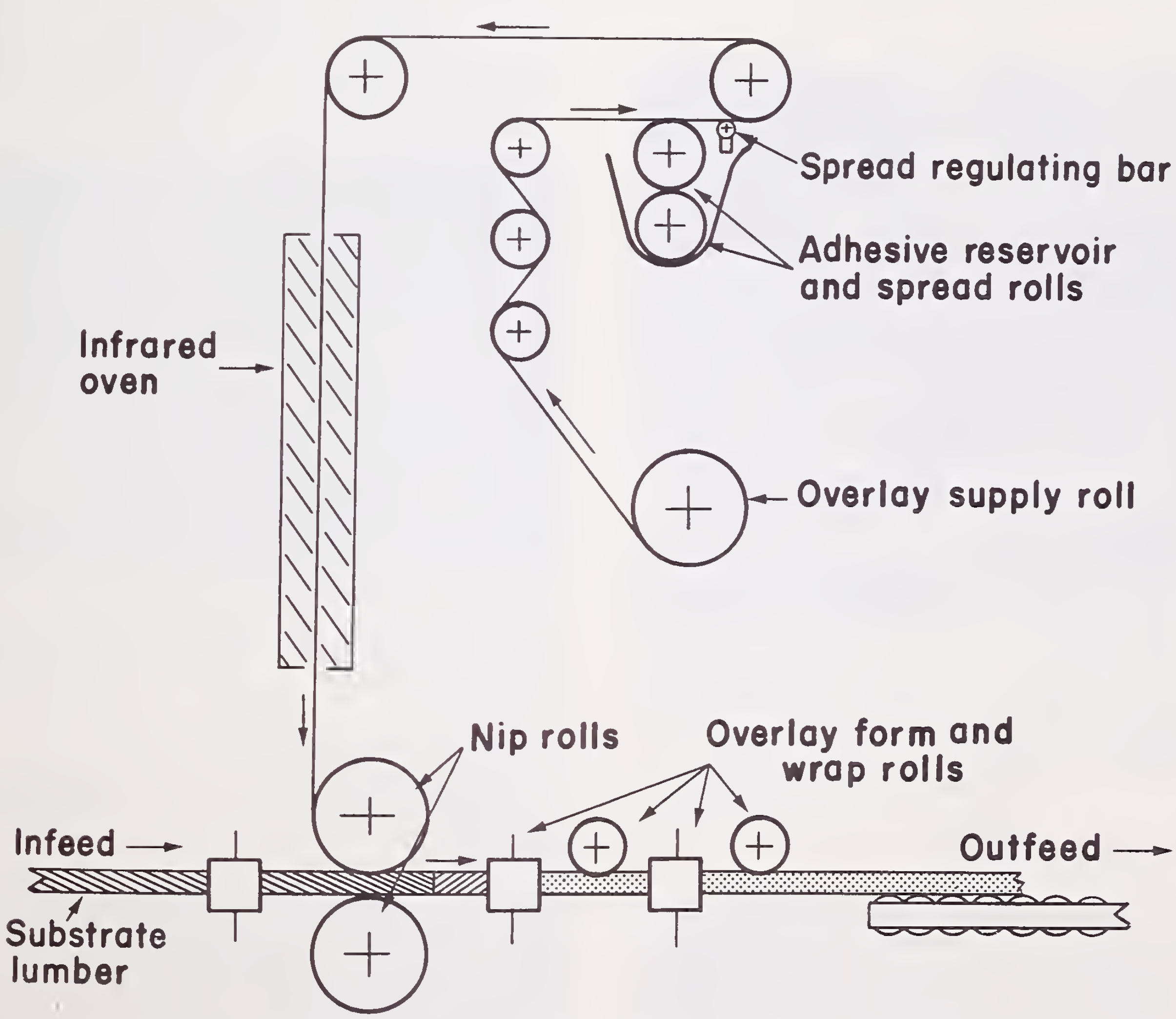


Figure 2.--A schematic drawing of the roll laminator illustrates how fiber overlay material, adhesive, and lumber are brought together in proper sequence.

passes through nip rolls. The laminator provides the coordinated mechanical systems necessary to feed overlay material, spread adhesive, tackify adhesive, feed lumber, and apply and wrap the overlay on the substrate (fig. 2). Adhesive is picked up from a supply trough by conventional spreader rolls. Paper is fed across the glue spreader roll and spread regulating bar. The adhesive-coated paper then passes through a bank of infrared heaters where it is dried to the proper tack, and is passed to the main nip roll. Lumber passes through infeed alinement rolls, through the main nip roll where the overlay is applied, and then through successive pairs of wrap rolls (fig. 3). The wrap rolls are mounted on a floating carriage to allow compensating movement for variation between boards. The laminator regulates adhesive spread, overlay web tension, heater temperature, and feed rate.

Major modifications to the basic machine included a power infeed system and a brush and vacuum lumber cleaning unit in the infeed line. An adhesive pump system was added to supply adhesive to the overhead trough, and an overhead hoist was installed to facilitate handling rolls of overlay material.

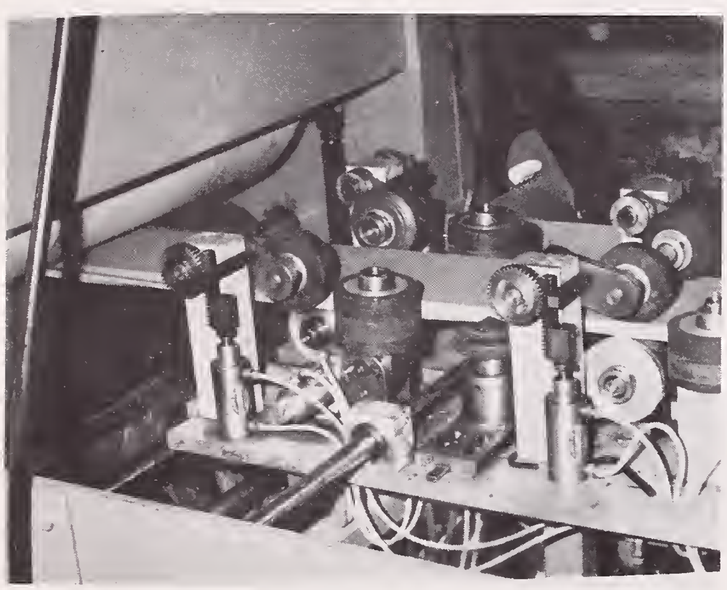


Figure 3.--The outfeed end of the roll laminator contains the roller system that wraps an overlay around the edges of the board.

Pilot Test Production Runs

Products manufactured in the pilot plant included overlaid 4/4 lumber of various widths, bevel siding, stadium seat stock, and window and door casing stock. In general, both product quality and rate of production were satisfactory for all of these products.

For beveled siding, 5/4 Common lumber was overlaid on both sides; one face and edge were overlaid on each of two passes through the laminator. The material was then resawn to a standard bevel siding pattern. Although precut bevel siding stock can be overlaid in the laminator, substantial mechanical modifications are required. Double-overlaying and resawing 5/4 flat stock is more convenient, providing damage to the overlay during resawing can be minimized. Bevel resawing lower grade knotty lumber can also be complicated by knots chipping, shattering, or deflecting the saw beyond allowable tolerances. Trials on unoverlaid lumber with a 30-inch standard bandsaw did not reveal any serious problems, however.

Stadium seat stock was produced without difficulty by applying the overlay to the top face, and wrapping around both edges of 8/4 stock. A special guide was installed on the laminator to help form the overlay around the added thickness.

Production of door and window casing stock was limited to relatively simple profiles at least 3½ inches wide, the minimum width for the pilot plant laminator. Because much of the lumber commonly used for trim items is of higher grade, such production would not contribute directly to the solution of the low-grade lumber problem. It could complete an overlaid siding or paneling system, however.

All production runs were made at machine speeds of 90 to 130 lineal feet per minute. The minimum practical speed for operation of the roll laminator is approximately 60 feet per minute. Short feasibility runs were made at speeds as high as 180 feet per minute.

Process Quality Control

A number of process conditions are potentially variable. Fluctuations in adhesive spread and heater temperature, lag or overshoot in control responses, and variation in substrate temperature and moisture content may affect product quality. Quality of the initial adhesive bond must be judged at frequent intervals during the production process, as a basis for making equipment adjustments. Later tests are needed to evaluate the quality of the cured glue bond.

Two quality tests developed by the Forest Products Laboratory were used extensively. The first employs a vacuum cup device to apply a lifting force to the overlay on any selected surface area (fig. 4). The device is particularly useful in testing bond quality over defects. The second is a variation of the established vacuum-

soak test procedure (initial vacuum, followed by half-hour soak, and subsequent ovendrying), to simulate a variety of use conditions.

Other quality control tests developed include a peel test and a whole-board soak test. As the name implies, the peel test consists of stripping the overlay from a board surface by hand and noting the fiber failure. This is perhaps the most useful test of initial adhesive bond, although it requires an experienced observer. Peel strength can be observed at frequent intervals during production as a quick check on bond adequacy. In the whole-board soak test, glue lines are subjected to all the interacting stresses that occur with major moisture content changes in the substrate. Results of exposure tests conducted to date correlate better with the whole-board soak test than with any other quality tests.

Achieving a desired level of product quality requires considerable experience, training, and attention to detail by the operator. The basic requirements for implementing quality control are:

1. Cleanliness of equipment, substrate, overlay, and adhesive.
2. Positive control of overlay tension.
3. Uniform spread of adhesive.
4. Accurate temperature control, coupled with precise speed control.

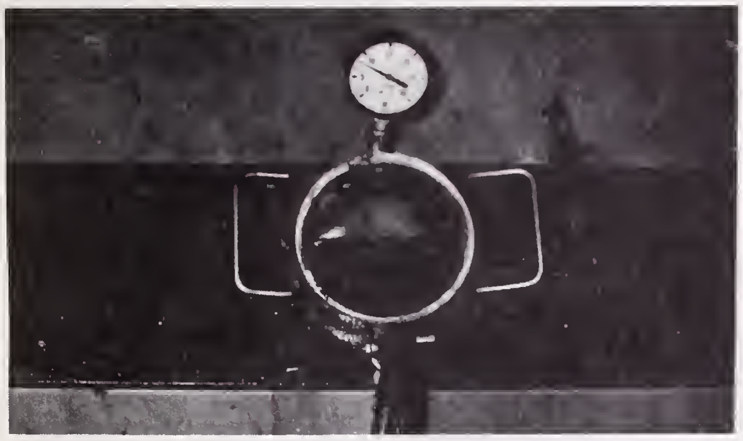


Figure 4.--A suction device provides a quick evaluation of initial overlay-to-substrate glue bond quality.

Production Costs

True costs of production are difficult to derive from pilot plant operations, since auxiliary equipment and conditions of production are usually somewhat primitive. Nevertheless, pilot plant costs can provide a factual basis for judging full production costs, and can focus attention on the relative importance of the various production factors.

Total costs of production include costs of the overlay and substrate, direct processing material and labor costs, and indirect equipment and facility costs. Only direct material and labor use per unit of production can be observed and measured during pilot plant operations; indirect costs and, to some extent, substrate costs must be estimated on the basis of probable operating conditions and alternatives.

Costs of overlay stock will vary with general lumber market conditions, and with the intracompany structure and affiliations. Assuming that the typical overlay operation will be a captive plant affiliated with a lumber-producing firm, lumber may be available at prevailing f.o.b. mill lumber prices. The ultimate cost of lumber

Table 3.--Estimated costs of overlayable substrates of ponderosa pine lumber by three alternatives

Input by grade number	Thickness	Width	F.o.b. mill value[1]	Alternatives[2] 1	2	3
	Inches		Dollars/M b.m.	Dollars/M sq.ft.		
D Sel[3]	8/4	RW	229	229		
2C[3]	4/4	6	106	106		
2C	4/4	8	98	98		
3C	4/4	8	73	73	124	95
3C	4/4	12	84	84	151	104
4C	4/4	8	57	57	315	106
4C	4/4	12	63	63	390	108

[1]5-year averages (1966-70) for dry, finished lumber at inland mills.

[2]Alternative 1 assumes that only lumber meeting overlay substrate specifications is selected from each grade; 2 assumes that lumber is purchased by mill-run grade, with lumber not meeting substrate specifications being resold at next lower grade (for example, cull from 3C sold as 4C); 3 assumes that lumber is purchased by mill-run grade, with repairable lumber chemically repaired and nonrepairable lumber resold at next lower grade. See appendix I for calculations of substrate cost under alternatives 2 and 3.

[3]D Select and 2 & Btr. grades considered for specialty products only (stadium seating, fascia); most of lumber in the grade would be an acceptable substrate.

for overlaying will depend on whether the overlay plant can obtain selected portions of each grade, or must purchase and use (by repairing or reselling) mill-run grade lumber. Long-term average f.o.b. mill values for mill-run grades of ponderosa pine lumber are shown in table 3,

along with estimated costs of overlayable lumber substrate under each of three operating alternatives.

A series of pilot plant runs of 1 to 4 hours' duration were made to facilitate estimating direct material and labor costs per unit of production (table 4). During each run a single product involving one substrate size and one overlay was processed. Direct consumption or use of materials and labor was recorded and related to quantity of overlaid product manufactured. The pilot plant runs also provided a means of measuring such costs as machine setup time, cleanup time, and operational delays.

Indirect costs were estimated as accurately as possible for two levels of production—single laminator operated one shift per day, and single laminator operated two shifts per day. Operating assumptions and cost schedules used are discussed in the appendix.

Total projected costs of manufacturing overlaid lumber products, including substrate and direct and indirect processing costs, are aggregated in table 5. Some of the direct processing costs shown are likely to be higher than they would be in a fully developed production operation. Factors that tend to increase costs in the pilot plant include:

1. Relative inexperience of the operating crew. The crew is "borrowed" from other mill duties to work with the laminator at infrequent intervals, and may consequently be less efficient than a full-time production crew.
2. Lack of modifications and mechanical improvements that could be made on the roll laminator. Presumably, a production operation could capitalize on all the mechanical improvements made or underway to date, plus others that might become apparent in sustained production.
3. Lack of efficient equipment and facilities for lumber infeed, outfeed, and paper and adhesive loading. A production operation would benefit from more efficient auxiliary equipment and facilities.

Table 4.--Direct material and labor used, and costs incurred in pilot plant trial operations[1]

Overlaid lumber	Lumber substrate		Overlay		Adhesive		Operating labor and supervision		Setup-cleanup labor	
	Units used	Dollars	Units used	Dollars	Units used	Dollars	Units used	Dollars	Units used	Dollars
Cost basis	M sq.ft.	([2])	M sq.ft	21.60	Pounds	0.45	Minutes	0.272	Minutes	0.046
1- by 8-inch										
Per M lineal feet	0.71	([2])	0.91	19.66	14.1	6.35	14.6	3.97	3.2	0.15
Per M square feet	1.06	([2])	1.37	29.59	21.2	9.54	21.9	5.96	4.8	.22
1- by 12-inch										
Per M lineal feet (and M square feet)	1.06	([2])	1.28	27.65	16.2	7.29	12.9	3.51	3.2	.15

[1]Pilot plant trial runs to establish production costs were made with 1- by 8- and 1- by 12-inch 4/4 lumber substrates, overlaid with 5-mil vulcanized fiber, single-face overlay, with both edges wrapped.

[2]Substrate costs depend on input grade and available operating alternatives (see table 3). Substrate use reflects an average trim loss of 5.7 percent of the overlaid product.

Table 5.--Total projected production costs, in M square feet, for selected overlaid lumber products[1]

Production cost item	1- by 8-inch product, using--		1- by 12-inch product, using--	
	Grade 3 Common	Grade 4 Common	Grade 3 Common	Grade 4 Common
Substrate:[2]				
Alternative 1	$ 77.38	$ 60.42	$ 89.04	$ 66.78
Alternative 2	131.44	333.90	160.06	413.40
Alternative 3	100.70	112.36	110.24	114.48
Direct processing:				
Overlay	29.59	29.59	27.65	27.65
Adhesive	9.54	9.54	7.29	7.29
Labor	6.18	6.18	3.66	3.66
Electrical power	.41	.41	.27	.27
Indirect:				
Equipment investment and depreciation				
Single shift	2.30	2.30	1.53	1.53
Double shift	1.15	1.15	.77	.77
Building and facilities				
Single shift	.51	.51	.34	.34
Double shift	.25	.25	.17	.17
Taxes, insurance, maintenance (6 percent times investment)				
Single shift	.59	.59	.39	.39
Dougle shift	.30	.30	.20	.20
Total production:				
Substrate alternative 1				
Single shift	126.50	109.54	130.17	107.91
Double shift	124.80	107.84	129.05	106.79
Substrate alternative 2				
Single shift	180.56	383.02	201.19	454.53
Double shift	178.86	381.32	200.07	453.41
Substrate alternative 3				
Single shift	149.82	161.48	151.37	155.61
Double shift	148.12	159.78	150.25	154.49

[1]Cost calculations based on pilot plant test experience, plus operating assumptions and schedules included in the appendix.

[2]Refer to table 3 and substrate cost calculations included in appendix I. Indicated costs include 5.7 percent trim allowance.

PHASE II:
EVALUATION OF LUMBER REPAIR TECHNIQUES

The Need for Repair

Lumber overlays presently available cannot successfully span voids of any consequence, and generally do not adhere well over planer skip or rough grain. The necessary exclusion of lumber with such defects accounts for the low recovery of overlayable lumber from Common grades (see table 2). The low recovery is of primary concern, and indicates that suitable lumber repair methods must be developed before the overlay process can economically upgrade low-grade lumber. Phase II of this study was initiated to develope and evaluate the technical feasibility of a number of methods of repairing defects in lumber.

Lumber Defects and Potential Repair Techniques

Major defects that affect lumber substrate acceptability are unsound or chipped knots, knotholes, and rough or torn grain. Other less frequent defects include splits, wane, bark, rot or pitch pockets, crook, and pith streaks with associated juvenile wood.

The character of lumber defects varies with both lumber grade and width. The larger and more severe defects allowed in the lower grades and wider widths are more difficult to repair. Frequency of defect occurrence, however, is relatively independent of grade, and is generally lowest per square foot of board area in the wider widths. Average repairable defect occurrence and size in grades 3 and 4 Common lumber are illustrated in table 6. Histograms (figs. 5, 6) illustrate the frequency of distribution of the repairable defects by size classes. Grade 5 Common lumber has such extensive "nonrepairable" defect (see table 2) that it cannot be considered a potential source of overlay material.

For the defects being considered, the most promising methods of repair include wood plugs or patches, chemical foam repair, abrasive planing, and selective cut-up. Wood plugs or patches can be quickly applied with equipment commercially available. Chemical patches such as urethane foams can also be applied automatically, and can conform to virtually any size and shape of open defect. Abrasive planing can reduce or correct shallow open defect such as rough or torn grain. Selective cut-up procedures can be used to remove nonoverlayable defects from either repairable or cull lumber. All of these potential repair methods were evaluated during the second phase of the study.

Table 6.--Average width, length, area, and number of defects that require repair in repairable Common grades 3 and 4 lumber[1]

Lumber width and grade	Average defect size: Width	Average defect size: Length	Average defect size: Area	Defects per square foot
	Inches	Inches	Sq.in.	No.
4-inch:				
Grade 3	1.27	4.61	5.40	1.438
Grade 4	1.47	6.97	11.27	1.701
8-inch:				
Grade 3	1.89	5.06	10.42	1.381
Grade 4	2.46	8.53	24.91	1.249
12-inch:				
Grade 3	2.33	5.18	13.75	.827
Grade 4	2.60	12.03	27.01	.845

[1]Data based on repairable proportion of each grade, as shown in table 2.

Each of the repair methods evaluated was generally limited in application to the types of defects for which it appeared best suited. Defect types for which specific repair methods were tested are:

Repair method	Applicable defect types
Wood plugging	Unsound knots and knotholes less than 1½ inches in maximum diameter.
Chemical repair	Unsound, chipped or broken knots; knotholes; wane and other small voids; bark, pitch, or rot pockets.
Abrasive planing	Torn, chipped, or rough grain.
Selective cut-up	Full range of defects, including splits, severe checks, etc., that cannot be repaired by other methods.

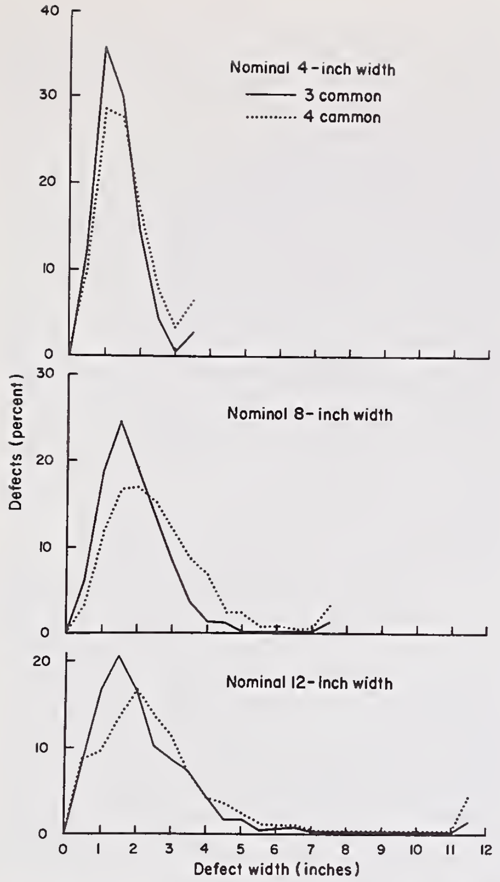


Figure 5.--Frequency of occurrence of defects, by defect width classes, in grades 3 and 4 Common ponderosa pine boards.

Pilot Tests of Repair Methods

Abrasive Planing

Abrasive planing tests were conducted with a double-belt combination sander-abrasive planer (fig. 7). Abrasive grits ranging from No. 24 to No. 100 were evaluated in various combinations on the double-belt unit at speeds up to 200 feet per minute. Accumulated data provided a basis for estimating abrasive planing capabilities in terms of feed rate, material removal, and surface characteristics for any belt combination.

An edge sander was added to the pilot production line to dress edge repairs and to provide for S4S abrasive finishing. Stock passed from the abrasive planer through the brush and vacuum lumber cleaning unit, and into the roll laminator.

Roll laminating requires a relatively smooth, unabraded surface; consequently, grits used are limited by the surface characteristics produced (fig. 8). Considering both production needs and surface acceptability, a combination of No. 36 grit (first belt) and No. 50 grit (second or smoothing belt) was found best for processing overlay stock.

Abrasive planing successfully "repairs" shallow defects such as planer skip, torn grain,

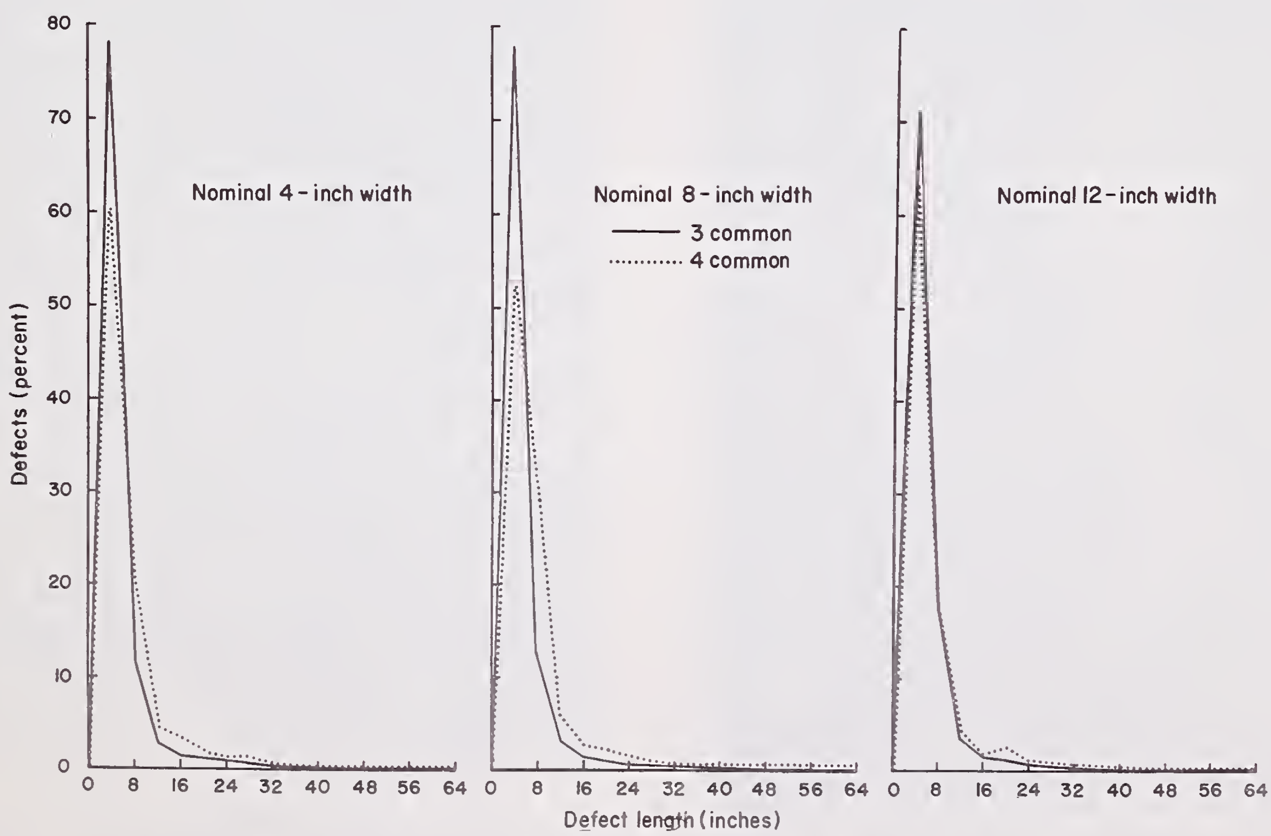


Figure 6.--Frequency of occurrence of defects, by defect length classes, in grades 3 and 4 Common ponderosa pine boards.

and the characteristic rough grain around knots (fig. 9). Abrasive planing also provides an ideal method of resurfacing patched lumber, because the wood or chemical patch must be machined down with minimal removal of stock from the board itself. The process also removes oxidized surfaces and pitch exudations, which improves the quality of the overlay glue bond. The slightly textured surface resulting from abrasive planing may also reduce the tendency of chemical patches to show through an overlay.

Ideally, rough lumber designated for overlaying would be abrasive planed, thus avoiding the rough and pulled grain defects caused by conventional knife planing. Abrasive planing is generally slower than conventional planing, however. A production alternative might be to surface material oversize with conventional planing, and complete surfacing to size with an abrasive planer.

The depth of defect that can be corrected by abrasive planing is limited by the specified minimal finished thickness of the stock. As a practical matter, abrasive planing is most effective in removing defects not exceeding 0.02 to 0.03 inch in depth (reducing 25/32-inch standard lumber to 3/4-inch). The removal of 0.02 inch of material from conventionally planed lumber successfully repaired all rough and pulled grain areas, and reduced thickness variation in the stock.

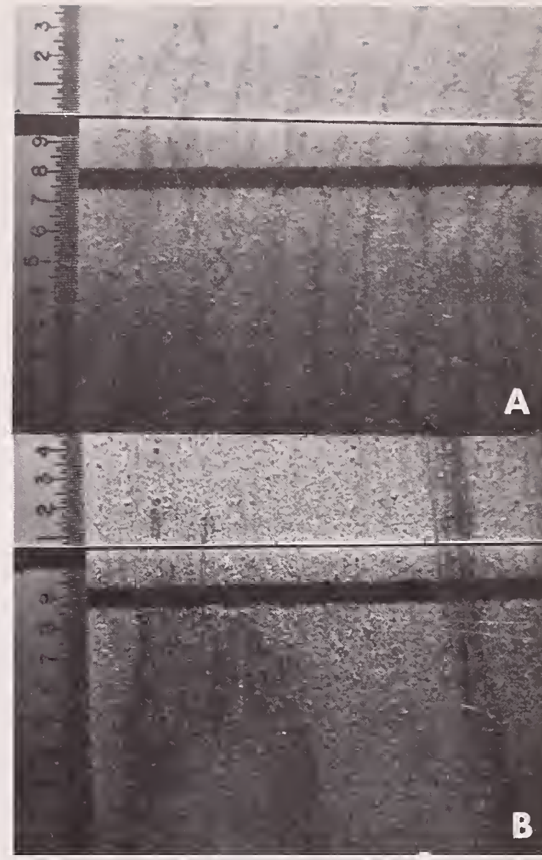


Figure 8.--Shadowlines magnify surface smoothness differences after sanding with No. 100 grit, A, and No. 50 grit, B, at a feed rate of 100 f.p.m.

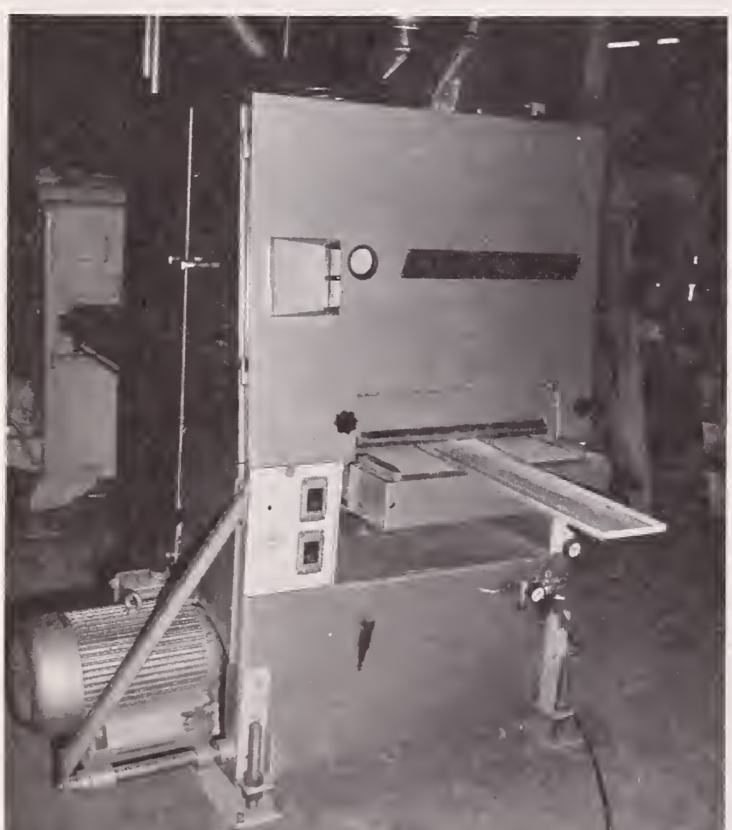


Figure 7.--The abrasive planer used in the study proved effective in repairing surface defects such as torn grain and planer skips.

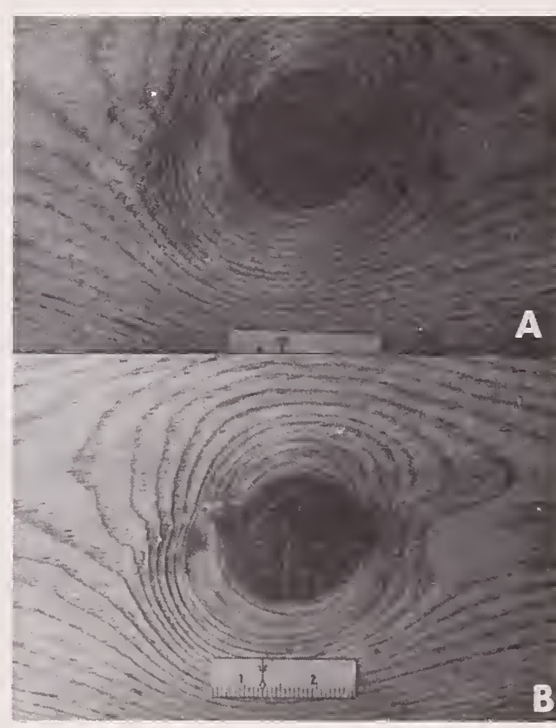


Figure 9.--Torn grain before, A, and after, B, a single pass through the abrasive planer, using No. 36 grit front sanding belt followed by No. 50 grit. Removal of 0.02 inch of material generally provided adequate repair.

Wood Plugging

Defects in lumber can be repaired by boring out the defect and inserting a wood plug, as in patching plywood panels. This method of patching was evaluated with a commercially available boring and plugging machine (fig. 10). The machine automatically bores out the defect (as positioned by the operator), sprays the hole with adhesive, cuts a wood plug, and positions it in the hole. A complete operating cycle requires 3 seconds. Boring depth and associated plug thickness can be varied, and multiple overlapping plugs can be inserted to replace larger defects.

A full range of patch thicknesses, including 5/32, 7/32, 3/8, and 25/32 inch, were tested. Plugs of 7/32-inch thickness proved to be the most convenient to install. Plugs the full thickness of the board are generally unsatisfactory because of a tendency of the boring bit to tear out the back perimeter of the hole. When plugs approaching half the board thickness (3/8 inch) are used, two-side patching can loosen or dislodge plugs set in the first side.

Wood plugging is a feasible means of repairing defects in lumber with relatively few, small defects (fig. 11). The wooden plugs are less noticeable on the board surface than synthetic patches, and have the same general texture as the board itself. Additional advantages are that plugging can be used for defects in the edge of the board (provided approximately two-thirds of the plug width is contained in the face of the board), and operation of plugging equipment requires little specialized training.

Wood plugging has the disadvantages of being relatively slow and expensive. Other disadvantages of plugging are restrictions in size and shape of defect that can be plugged, and slight separations that may develop around the plug. Any mismatch in grain direction and angle between board and plug results in slight separations around the patch, which contributes to showthrough and, under certain conditions, to overlay failure in the overlaid stock (fig. 12). Some tendency for the plug circumference to show through an overlay is apparent even in well-matched patches.

Although multiple plugs can be installed, experience indicates that they may not perform well. Each plug tends to force additional adhesive under the preceding plugs, raising them and creating a stairstep effect. For practical purposes, the size of defect that can effectively be plugged is limited by the size of the plug used. Equipment tested in the pilot plant used 1-9/16-inch plugs to repair defects up to approximately 1½-inch in diameter. This size plug will completely repair only about one-third of the boards in the 2 Common grade. Equipment is commercially available with 3-inch plugging

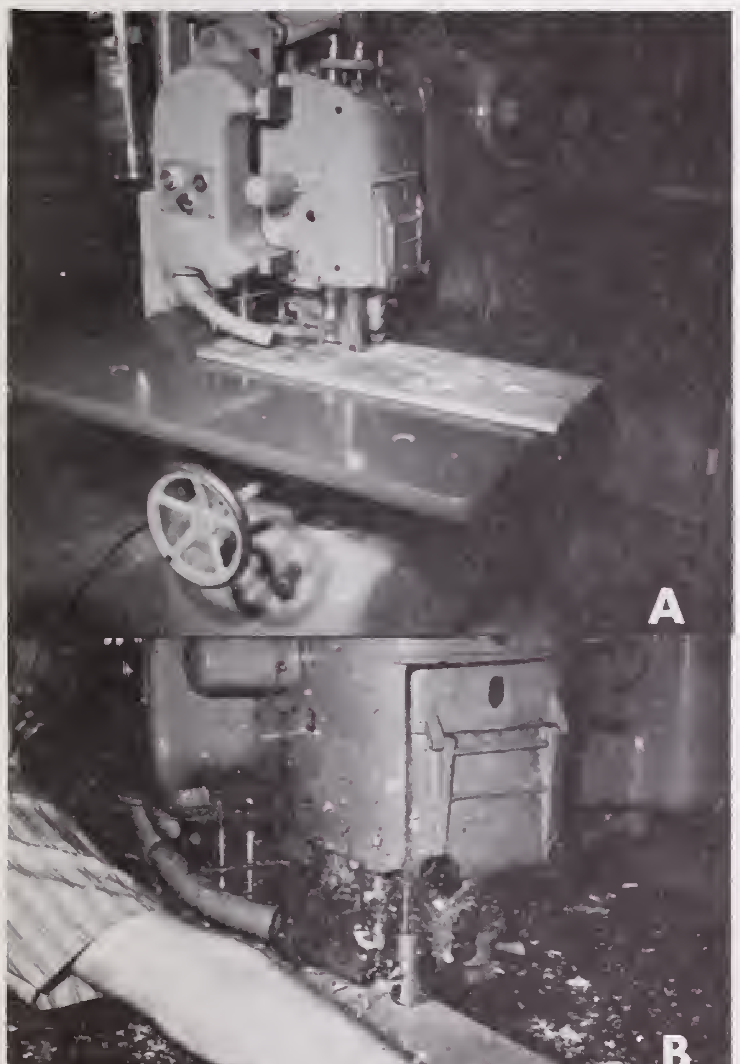


Figure 10.--Lumber plugging machine, A, bores out the defect, B, cuts a patch to size, applies adhesive, and sets the patch in a single sequenced operation.

Figure 11.--Wood plugs can be used to repair defects within the board, or on the edges of the board, provided approximately two-thirds of the plug is within the board.

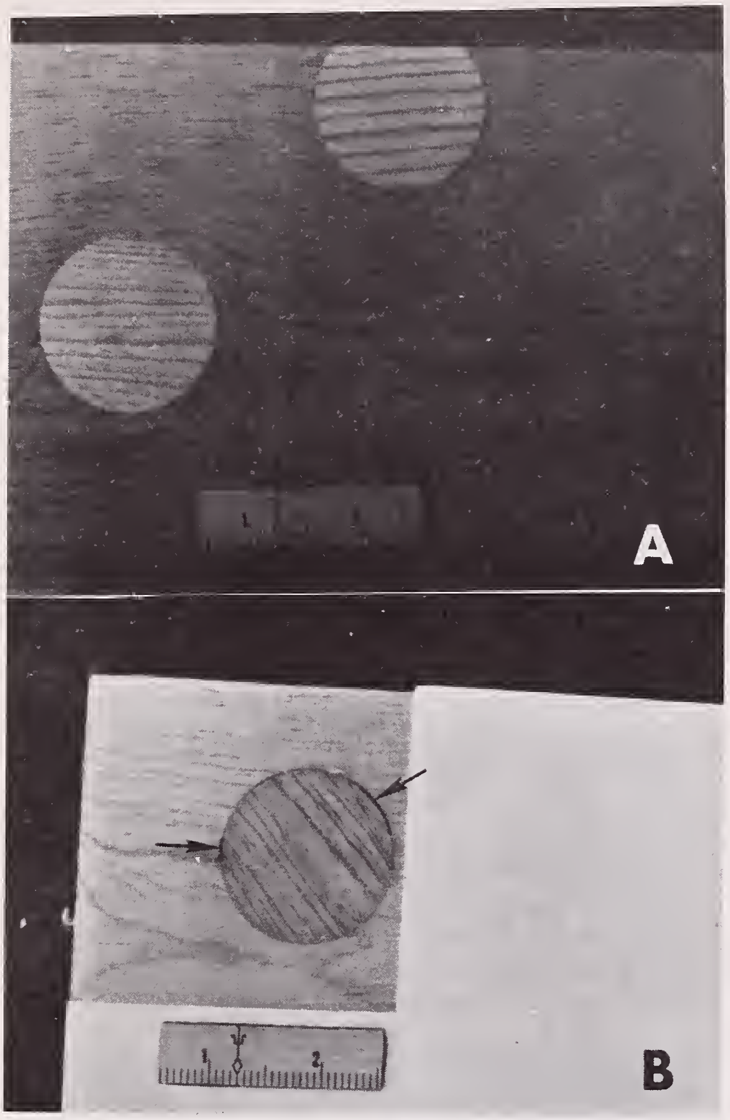


Figure 12.--Examples of matched and mismatched grain between plug and board. Well-matched grain, A, minimizes occurrence of gaps between plug and board, B, due to differential shrinkage.

capability, however, and with two heads accommodating two plug sizes. This larger equipment could repair practically all the defects in grade 2 Common lumber, creating a repaired, clear surface grade. The process is not a feasible repair method for grades 3 and 4 Common lumber, however, since too many of the defects exceed the capabilities of even the larger plugging equipment.

Costs of repairing lumber by plugging are high because of the relatively small amount of material that can be processed in a given period of time. One man operating one plugging unit can repair approximately 2,000 lineal feet (equivalent to 1,333 square feet) of 1- by 8-inch stock per 8-hour shift. Estimated costs of repairing such grade 2 Common lumber are itemized in table 7.

Table 7.--Estimated costs, per M square feet, of repairing grade 2 Common boards with wood plugs[1]

Cost item	Repair costs	
	Single shift	Double shift
Wood plug strips	$ 9.00	$ 9.00
Adhesive	1.00	1.00
Labor-- semiskilled (1 man)	18.00	18.00
Equipment depreciation	14.52	7.26
Power, facilities, miscellaneous equipment, etc.	1.00	1.00
Refinish (planer)	4.50	4.50
Subtotal	48.02	40.76
Adjustment for material loss, contingency, etc. (costs times 0.11)	5.28	4.48
Total	$53.30	$45.24

[1]Pilot plant tests limited to 1- by 8-inch stock in which all defects could be repaired with 1-9/16-inch plugs. Operating assumptions and labor, equipment, and facility costs based on schedules included in the appendix.

Chemical Repair

Synthetic repair materials have been used to some extent to fill open defects in other wood products (plywood and so forth), and can be used in lumber. A primary requirement difference between synthetic repair materials for plywood and lumber is the need for lumber patching materials to "move" freely with dimensional changes in the board. Patching materials for overlay substrates must also provide a good surface for adhesion and create minimal show-through. They must also saw, machine, and nail in approximately the same manner as wood.

Early work with chemical repair techniques established that some routing or machining was necessary to "clean up" knotholes and other defects, and provide a firm surface for patch adhesion. Chemical patching (fig. 13) consequently involves a series of steps as follows:

1. Locating and identifying a patchable defect.
2. Routing or machining out the defect, leaving clean, solid wood at the perimeter.
3. Metering catalyzed repair chemical into the void.

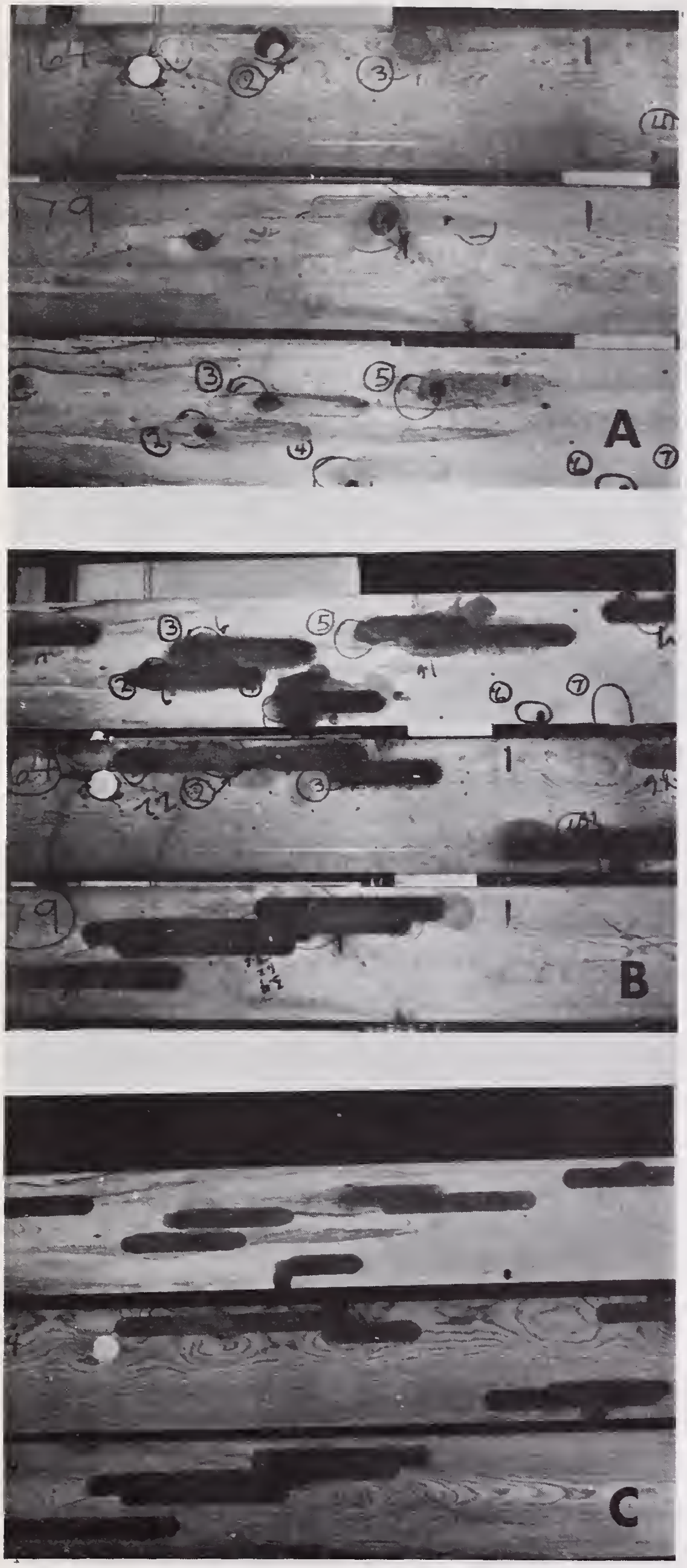


Figure 13.--A sequence of photos illustrates steps in the foam repair process: defects have been routed for repair, A; routed areas have been filled and allowed to set under pressure, B; repaired boards after a cleanup pass through the abrasive planer, C.

4. Applying a restraint against which the foam can expand, as a means of controlling density. (Most urethane foam systems have a free-rise foam density on the order of 2 to 10 pounds per cubic foot; consequently, restraint must be applied to achieve desirable patch densities of 18 to 20 pounds per cubic foot.)
5. Planing or sanding the repaired board to remove excess patch material and provide a smooth, uniform surface.

The urethane foams best satisfy all of the criteria for a chemical lumber repair material. They can be formulated to set in a matter of seconds, a necessity for production line processing.

A total of 18 urethane and similar resin systems were initially evaluated by the Forest Products Laboratory. Of four recommended for further evaluation in the pilot plant, two performed satisfactorily in the pilot trials.

Two significant variables in chemical repair were "packing" or patch density, and hole-edge geometry. Patch density can be varied by formulation, and by amount of resin loaded under restraint. Hole-edge geometry can be varied from a straight, vertical cut to a variety of tapered and shouldered cuts (fig. 14).

Figure 14.--Two variations of hole-edge geometry -- 1/8- and 1/4-inch shoulders -- were used in preparing defects for foam patch application. Test data indicated a slight advantage with the wider shoulder.

Extensive tests were conducted to evaluate two foam densities (18 to 20 and 28 to 30 pounds per cubic foot) and three hole-edge patterns (straight, 1/8-inch shoulder, and 1/4-inch shoulder). Evaluations indicated that both densities of foam performed very satisfactorily, with the lighter foam showing slight advantage.

Shouldered patches also performed better than straight patches, with test evidence slightly favoring the wider 1/4-inch shoulder. All final patching tests were made with the lighter foam density and both 1/4- and 1/8-inch shoulders. Very few patches failed and all failures were minute (fig. 15).

Commercial use of chemical patching methods would require a high degree of automation in locating, machining, and repairing defects. While the primary objective of the repair phase of the study was to establish a technically feasible method, methods of automatically locating and routing defects were also investigated. Scanners now in use for automatic veneer clipping were found to be generally satisfactory for lumber defect scanning, although the recognition pattern against which scanner information is checked would have to be modified to meet lumber repair requirements. Equipment suppliers have indicated that, with their present experience in plywood veneer scanning, automatic lumber scanning systems could easily be developed to control routing equipment as desired.

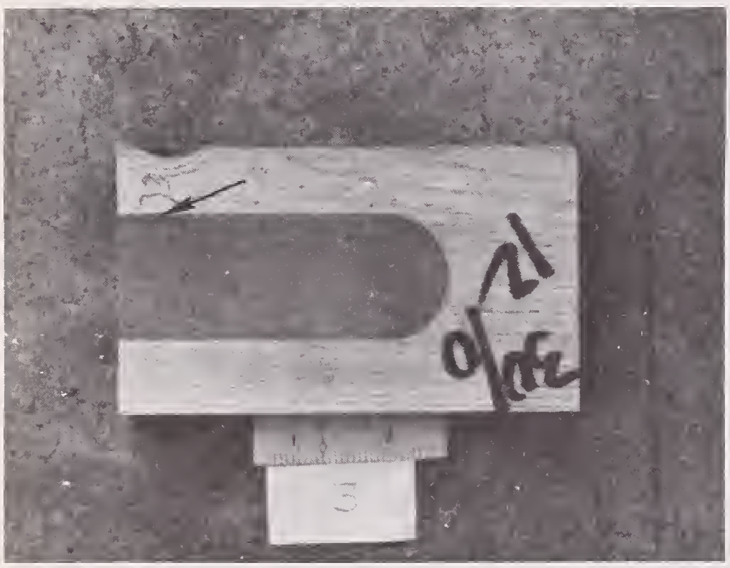


Figure 15.--The relatively obscure edge failure (arrow) which rejected this sample illustrates the rigid test requirements followed in evaluating potential repair materials.

An improvised optical scanning and routing system was devised with a single photocell and router (fig. 16). The router, a 2-3/4 horsepower, 23,000 r.p.m. unit, was mounted downstream from the scanner on a pneumatically actuated swinging arm. Signals generated by the scanning photocell activated the router to rout out defects. The rudimentary system operated successfully at feed rates of 90 to 100 feet per minute, routing up to 0.3 inch deep and 1¼ inches wide. A commercial operation would probably employ a bank of photocells, each scanning a proportion of the width of the board, and each controlling a downstream router. In this manner, defects located anywhere on the board and defects wider than a single router bit could be spotted and machined.

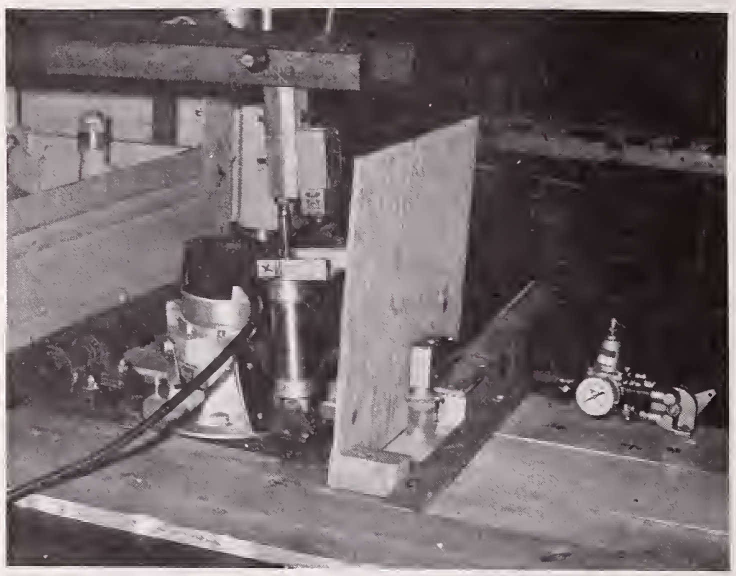


Figure 16.--A scanning photocell and router unit were used to locate and rout defects in the chemical repair study. The photocell, mounted ahead of the plywood baffle, activates an air cylinder which in turn raises and lowers the router at the proper time.

Most foam systems are fast-reacting two-component systems, in which the components must be precisely measured and mixed immediately before application. Foam patching consequently requires special equipment to meter the components, mix them, and dispense the catalyzed material. Pilot plant foam patches were made with a commercial urethane foam dispenser (fig. 17). The dispenser automatically meters and mixes the components, and provides for either manual or automatic dispensing of calibrated quantities or "shots" of the patching material. This type of air-operated high-speed mixer tends to introduce some air into the foam, however, causing nonuniform cell structure in the patches. Other commercially available mixing units may be more desirable for production use.

Chemical foam repair methods have the advantages of accommodating a wider range of size and type of defect than other methods, while providing a tight patch. Edge failure of the patches (fig. 15) is unusual, and generally indicates improper formulation, poor machining, or errors in patching technique. Durability and adhesion typically are excellent.

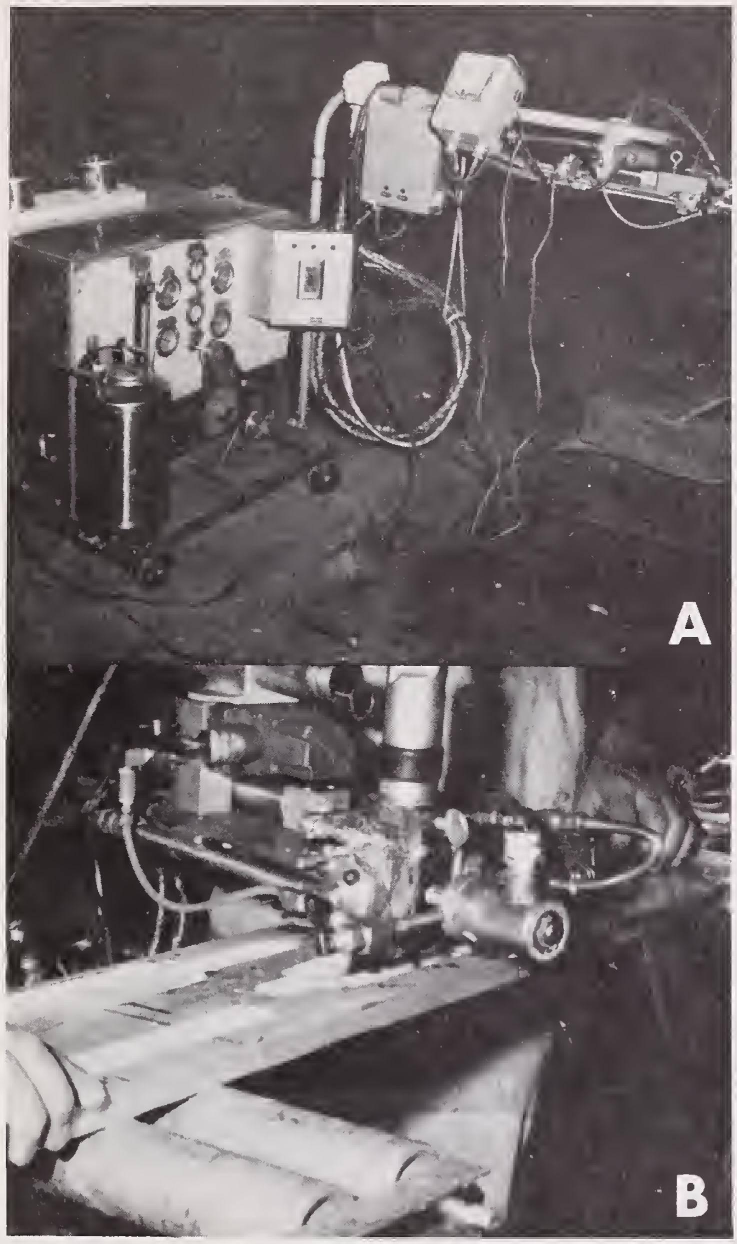


Figure 17.--Foam dispenser, A, and mixing and discharge assembly, B. The system automatically meters and mixes the components, and dispenses calibrated quantities of patching material.

Disadvantages of the method are that it requires a higher degree of quality control and technological sophistication than other methods, and requires considerably more specialized equipment. Because the foam patch material presently available is less hygroscopic than the surrounding wood, roll laminating overlays over the patches requires some adhesive and equipment modifications. Foam patches also tend to show through overlays because of differences between patch and wood texture. Showthrough resulting from foam patches, as well as knots and wood patches, can be minimized by abrasive planing, however.

The chemical repair work was carried out to evaluate the technical rather than economic feasibility of promising repair materials and methods. Costs that would be incurred in a commercial chemical repair operation can be estimated, however, by assuming use of an automated defect-locating and repair system based on equipment currently available commercially. Under such an assumption, estimated costs of chemically repairing grades 3 and 4 Common lumber are shown in table 8. Assumed production and cost schedules are included in the appendix.

Selective Cut-up

Low-grade lumber can also be repaired by ripping and crosscutting to remove unacceptable defects. Semiautomatic cut-up and end- and edge-gluing technology has been used for years in cut stock and lumber panel operations. Cuttings can thus be reassembled to produce an overlayable board or panel of practically any desired dimension. Overlaid panel products wider than conventional boards would have distinct marketing advantages. The width of overlay stock made up from cuttings would be limited only by the capacity of the roll laminator itself.

The feasibility of a low-grade lumber cut-up operation depends heavily upon the quantity and size of overlayable cuttings that are recoverable. To evaluate effects of board grade and width upon recovery, a method of reiterative simulated cut-up was developed. A sample of 600 boards was selected, representing widths of 4, 8, and 12 inches in grades 3 and 4 Common. The boards were examined, nonoverlayable defects located and outlined, and the boards photographed. Photos of the boards were projected at half-scale, and X and Y coordinates of all nonoverlayable defects measured and recorded in ¼-inch units. Board identification and defect coordinate data were transferred to punch cards for computer analysis.

A computer program[3] was written to calculate cutting recovery from individual sample boards, within constraints on cutting width combinations and cutting length. The program includes two basic routines, one to determine all possible permutations and combinations of specified sizes of cuttings for a board, and a

[3]*Erickson, Bernard J., and Donald C. Markstrom. Predicting softwood cutting yield with the computer. (Manuscript being prepared at Rocky Mountain Forest and Range Experiment Station.)*

Table 8.--Estimated costs,[1] per M square feet, of chemically patching repairable grades 3 and 4 Common boards, in 8- and 12-inch widths

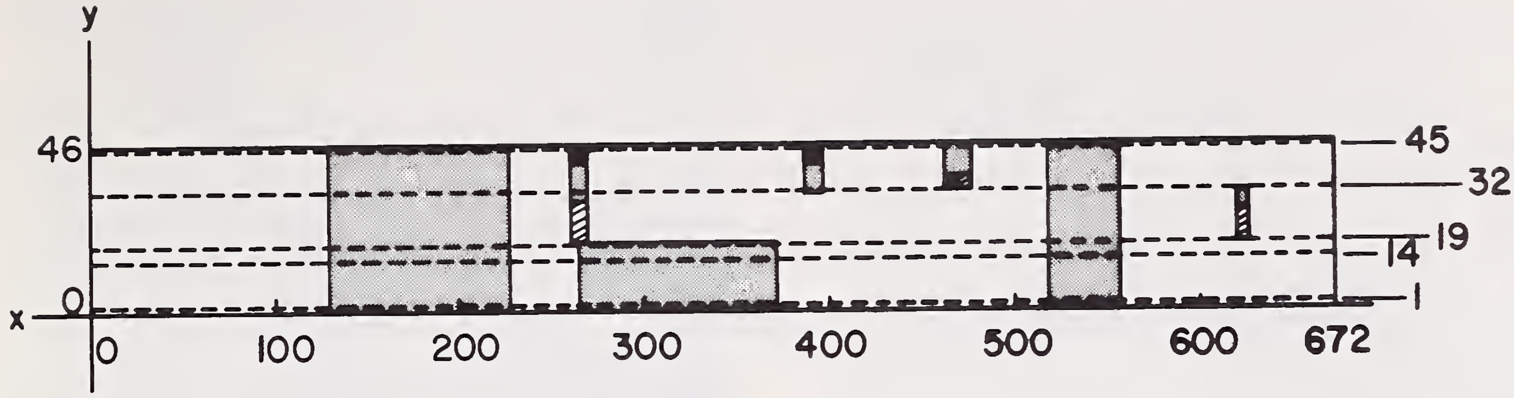
Cost item	1- by 8-inch product		1- by 12-inch product	
	Grade 3	Grade 4	Grade 3	Grade 4
Urethane foam	$14.50	$29.00	$11.60	$21.50
Labor:				
Supervisor (shared)	.70	.70	.70	.70
Skilled (1 man)	.91	.91	.91	.91
Unskilled (3 men)	1.65	1.65	1.65	1.65
Equipment depreciation:				
Single shift	3.78	3.78	3.78	3.78
Double shift	1.89	1.89	1.89	1.89
Electrical power	.27	.27	.27	.27
Building and facilities:				
Single shift	.68	.68	.68	.68
Dougle shift	.34	.34	.34	.34
Taxes, insurance, maintenance:				
Single shift	.96	.96	.96	.96
Double shift	.48	.48	.48	.48
Miscellaneous supplies, equipment:	1.00	1.00	1.00	1.00
Subtotal				
Single shift	24.45	38.95	21.55	31.45
Double shift	21.74	36.24	18.84	28.74
Adjustment for material loss, contingency, etc. (costs times 0.11)				
Single shift	2.69	4.28	2.37	3.46
Double shift	2.39	3.99	2.07	3.16
Total				
Single shift	27.14	43.23	23.92	34.91
Double shift	24.13	40.23	20.91	31.90

[1]Operating assumptions and labor, equipment, facility, and power costs based on schedules included in the appendix.

second to locate the cuttings on the individual board to maximize recovery (fig. 18). Program output indicates total loss area (including defects, saw kerfs, and edge trim) and total recovered area.

Table 9 describes maximum overlayable cutting recovery, and distribution by cutting widths, for lumber of grades 3 and 4 Common. As expected, the quantity of overlayable cuttings recoverable increases as the minimum allowable length of cutting is reduced, and as lumber grade increases. The lower recovery from nonrepairable boards (that is, those which were obviously too defective for conventional repair) is also to be expected. The lower recovery from the 8-inch boards resulted from an original program constraint that the number of saw kerfs on the board must equal the number of cutting widths. A subsample of 8-inch boards yielded approximately 8 percent more total recovery when the constraint was changed so that the number of saw kerfs on the board could be one less than the number of cuttings. The additional 8 percent recovery for the 8-inch boards makes the total recovery very comparable with the 4- and 12-inch boards.

A lumber defect scanning system such as that used in chemical repair trials could be



Board Grade: 4C
Width: 11-1/2 inches (46 units)
Length: 14 feet (672 units)
Coordinates: (0,0) (46,672)

Cutting Widths: 1, 2, and 3 inches
Length: 9 inches +

Optimum Cutting Widths and Sequence: 3, 1, 3, and 3 inches
Saw Kerf Coordinates: 1, 14, 19, 32, 45, and 46
Area Recovered: 19,404 sq. units
Area of Board: 30,912 sq. units
Percent Recovery: 62.77 percent

Defect Coordinates:
1. (0,127) (46,222)
2. (29,259) (38,265)
3. (0,262) (19,370)
4. (33,386) (41,396)
5. (35,463) (46,475)
6. (0,519) (46,556)
7. (27,620) (31,625)

Figure 18.--Diagrammatic sketch of a grade 4 Common 1- by 12-inch board, with associated program output data, illustrates the program developed for selective cut-up evaluation. Shaded areas represent defects that have been located by X-Y coordinates and blocked out. Lined areas represent additional material lost in cutting out defects.

combined with the optimizing computer program and an automatic-set ripsaw to automate the entire cut-up process. A fully automated cut-up system could substantially improve cutting quality and yield over that achieved by present methods, as well as increase potential production rates.

The optimizing cut-up program has considerable potential for application beyond the needs of the immediate study. The same basic techniques of automated defect scanning and computer evaluation of cutting alternatives can be extended to many other milling or cutting operations such as edging, trimming, molding, and cut stock production.

Overlaying On Repaired Lumber Substrates

Overlays may be applied to lumber repaired with wood plugs without any modification of materials or technique. Wood patches or plugs tend to show through 5-mil overlays, however, and the overlay may develop hairline failures around the edges of the plug. Both showthrough and overlay failure are minimized by matching texture and grain direction of board and plug.

Overlays applied to chemically repaired lumber with standard water-base adhesives may develop blisters over the patches, because excess moisture in the adhesive is not absorbed by the nonhygroscopic patch surface as it is by the wood. Use of a nonwater-base adhesive appears to be an easy solution, but it would require some modification of the laminator, depending on the specific type of adhesive selected. Another possible solution is to expand the overlay prior to application, by dampening or humidifying. The overlay would then be laminated in a fully expanded condition, however, and might fail in tension during any subsequent expansion of the substrate. A third solution would be to develop a more hygroscopic repair material, either by modifying the structure of the material or by adding hygroscopic fillers.

Table 9.--Maximum recovery of overlayable cuttings from mill-run and nonrepairable grades 3 and 4 Common lumber[1]

Lumber width and grade	Cutting constraints by minimum lengths and widths recovered														
	9-inch length					18-inch length					36-inch length				
	Inches wide 1	2	3	Total[2]	Basis: boards	Inches wide 1	2	3	Total[2]	Basis: boards	Inches wide 1	2	3	Total[2]	Basis: boards
	- - - Percent - - -				No.	- - - Percent - - -				No.	- - - Percent - - -				No.
MILL-RUN															
4 inches:															
Grade 3	24	50	1	75±0.7	100	22	46	2	70±0.9	100	17	38	1	56±1.4	100
Grade 4	21	43	1	65±1.6	100	18	38	1	57±1.7	100	14	26	1	41±2.0	100
8 inches:[3]															
Grade 3	31	28	8	67±0.7	100	27	25	10	62±1.1	100	22	18	8	48±1.7	100
Grade 4	25	22	9	56±1.8	100	22	21	6	49±1.8	100	14	15	5	34±1.7	100
12 inches:															
Grade 3	3	20	53	76±0.8	100	2	18	50	70±1.1	100	2	16	41	59±1.4	100
Grade 4	2	18	44	64±2.1	100	2	17	39	58±2.0	100	2	12	31	45±2.0	100
NONREPAIRABLE															
4 inches:															
Grade 3	22	49	0	71±2.0	16	19	44	0	63±2.9	16	14	35	0	49±3.6	16
Grade 4	20	40	2	62±1.8	54	16	35	2	53±1.9	54	12	21	2	35±2.2	54
8 inches:[3]															
Grade 3	24	27	5	56±3.2	17	22	18	9	49±3.6	17	14	13	7	34±4.3	17
Grade 4	18	18	8	44±4.1	27	16	17	5	38±3.8	27	11	13	4	28±3.6	27
12 inches:															
Grade 3	2	15	46	63±4.9	7	4	7	45	56±3.9	7	2	11	32	45±5.6	7
Grade 4	1	18	40	59±3.1	30	2	16	35	53±2.7	30	2	11	25	38±2.7	30

[1]Selected combinations analyzed were limited to combinations of 1-, 2-, and 3-inch cuttings, with the wider cuttings favored to the extent possible.
[2]Totals shown are class means ± one standard error.
[3]Recovery was about 8 percent higher with different program restraints; see text.

Performance Tests of Overlaid Lumber Products

Performance and durability of overlaid products manufactured by the roll lamination process are now being evaluated in exposure tests. The products being tested represent a range of Common lumber grade substrates, both repaired and unrepaired, and both prefinished and conventionally painted. Painted samples were finished with a titanium lead primer followed by two top coats of either acrylic latex or oil-base exterior white paint.

Product performance is being evaluated under a wide range of use conditions. Undesirable product performance may be characterized by actual delamination and physical degradation, or by objectionable visual features. Exposed products will be periodically examined to evaluate condition and performance of substrate (including repairs), overlay, adhesive bond, and finish. Figures 19 and 20 illustrate test installations established to observe the performance of overlaid siding under a variety of use conditions. Overlaid product samples are also exposed on test fences near Albuquerque, New Mexico, and Flagstaff, Arizona. Performance of test materials has been favorable to date.

Figure 19.--Test installations of overlaid lumber siding produced in the study include a storage structure in Fort Collins, Colorado, A, and a gaging station on an experimental watershed near Flagstaff, Arizona, B. Test material, 5-mil vulcanized fiber on overlayable grades 3 and 4 Common ponderosa pine lumber, was installed in 1968.

Figure 20.--Other test installations of overlaid siding involved additional species and siding patterns: southern pine drop siding installed near Diboll, Texas, in 1964, A, and grade 2 Common western white pine bevel siding installed at Wilmington, Delaware, in 1968, B and C. Five-mil vulcanized fiber was used as the overlay on all test structures.

CONCLUSIONS

Technical Feasibility and Cost

1. The roll-laminating fiber overlay process is a technically feasible method of upgrading lumber that meets substrate requirements.
2. The low recovery of overlayable lumber from mill-run Common grades dictates that lumber defects must be repaired in the upgrading process to avoid excessive substrate costs.
3. Chemical repair methods are technically feasible and offer the greatest potential.
4. The wood plug repair method is also technically feasible, but is restricted in type and size of defect that can be repaired.
5. Abrasive planing successfully repairs or eliminates surface defects such as torn, pulled, or rough grain, minor skip, etc. It also improves the general surface characteristics of the lumber for subsequent overlaying.
6. Projected total costs of manufacturing overlaid lumber products, from either selected or chemically repaired substrate lumber, range from \$107 to \$161 per thousand square feet (table 10).
7. Commercial feasibility is currently restricted by the need for a better automated defect scanning and repair process. Adhesive systems better suited for overlaying on chemical foam patches are also needed.

Table 10.--Summary of projected production costs per M square feet for overlaid lumber products from selected or repaired substrates[1]

Cost item	1- by 8-inch product	1- by 12-inch product
Substrate	$60.00-112.00	$67.00-114.00
Overlay	29.59	27.65
Adhesive	9.54	7.29
Labor	6.18	3.66
Power	.41	.27
Indirect costs (Facilities, equipment, etc.)	1.70-3.40	1.13-2.26
Total product cost range	107.00-161.00	107.00-155.00

[1]Tables 3, 4, and 5 give detailed production costs by lumber substrate grade and use alternative.

Marketing Outlook

1. The basic concept of overlaid lumber products is generally acceptable to many potential users if the product affords distinct performance and/or price advantages.

2. Stronger market receptivity will depend upon future market development activities and improved manufacturing methods to reduce costs. Presently, the best prospects are for individual firms to develop smaller volume markets for specialty products.

3. Costs of production using repaired substrates, a necessity under most operating circumstances, restrict marketing possibilities to the higher value end products. Costs of overlaid products and currently used competitive products are compared in table 11.

Table 11.--Estimated production costs per M square feet of selected overlaid lumber products and f.o.b. mill prices of competitive wood products

Basic product	Overlaid product		Competitive commercial products	
	Description	Cost[1]	Description	Mill price[2]
Bevel siding, 10-inch	5-mil vulcanized fiber on repaired grade 3 Common, 1- by 10-inch[3]	$150	(1) Redwood,V.G.,3/4- by 10-inch (2) Cedar,Clear,3/4- by 10-inch (3) Hardboard lap, primed	$213 220 170
Board or standard pattern siding, 12-inch	5-mil vulcanized fiber on repaired grade 3 Common, 1- by 12-inch	151	Redwood,V.G., 1- by 12-inch	325
Fascia, 6-inch	5-mil vulcanized fiber on grade 2 Common, 1- by 6-inch	166	(1) Redwood,Clear, 1- by 6-inch (2) Pine,D Select, 1- by 6-inch	270 201
Stadium seating:	10-mil vulcanized fiber on 8/4 D Select:		Redwood Ht.,V.G.:	
6-inch	2- by 6-inch	307	2- by 6-inch	365
12-inch	2- by 12-inch	292	2- by 12-inch	395
Industrial shelving	5-mil vulcanized fiber or equivalent on repaired grades 3 and 4 Common, 1- by 12-inch	153	(1) Particleboard, 3/4-inch (2) Plywood, A-C, 3/4-inch	95 180

[1]Total estimated production cost, not including allowances for profit and risk.
[2]Industry average f.o.b. mill prices, 1971 (presumed to include allowances for profit and risk).
[3]Overlaid bevel siding can also be produced by overlaying both sides of repaired 5/4 lumber and resawing, at a total estimated cost of $143/M square feet.

RECOMMENDATIONS

The study and conclusions reported here satisfy, and in some instances extend beyond, the objectives initially proposed for the pilot-plant investigation. The pilot operation has established the basic technical feasibility of the processes, but at the same time has indicated need for further development in several areas. Since overlaying and lumber repair, both separately and together, offer wide potential application, further development work is warranted. Recommendations include:

1. Develop an effective automated defect detection system to scan and control chemical repair of defective lumber.
2. Identify and test adhesive systems most suitable for overlaying chemical foam patches.
3. Evaluate the feasibility of using a foam adhesive to simultaneously make minor repairs and bond the overlay to the substrate.
4. Conduct further basic investigations of repair and overlay techniques in a facility where close control can be exercised over all aspects of substrate conditioning, in-plant operating conditions, and product testing.
5. Guide further work in repair and overlaying by the results of long-term tests of overlaid material now installed on test buildings and fences.
6. Evaluate in detail potential markets for specialty products for which repaired and/or overlaid lumber has unique advantages.

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APPENDICES

I. CALCULATED LUMBER SUBSTRATE COSTS

ASSUMPTIONS:

1. Lumber is available to the overlay operation at prevailing f.o.b. mill prices.
2. Lumber culled from each grade is resalable at f.o.b. mill price for next lower grade.
3. Under the repair alternative, lumber acceptable for repair is chemically repaired in a single-shift operation.

F.o.b. mill value, in M square feet, and substrate recovery, grades 3 and 4 Common ponderosa pine 4/4 lumber

Lumber width and grade	F.o.b. mill price	Substrate recovery		
		Acceptable	Repairable	Nonrepairable
		Percent		
8-inch:				
Grade 3	73	24	67	9
Grade 4	57	8	59	33
12-inch:				
Grade 3	84	24	67	9
Grade 4	63	8	59	33

Estimated cost of overlayable substrate from mill-run grades 3 and 4 lumber, by 8- and 12-inch widths

Cost item	1- by 8-inch product		1- by 12-inch product	
	Grade 3	Grade 4	Grade 3	Grade 4
Alternative 2 (without repair):				
Initial cost, M b.m.	$ 73.00	$ 57.00	$ 84.00	$ 63.00
Less resale value[1]	43.32	31.79	47.88	31.79
Net cost of overlayable lumber	29.68	25.21	36.12	31.21
Cost per board foot (or square foot)	0.1237	0.3151	0.1505	0.3901
Cost per M square feet	123.70	315.10	150.50	390.10
Alternative 3 (with chemical repair):				
Initial cost, M b.m.	73.00	57.00	84.00	63.00
Plus cost of repair[2]	18.09	25.37	16.08	20.65
Subtotal	91.09	82.37	100.08	83.65
Less resale value[3]	5.13	11.40	5.67	11.40
Net cost of overlayable lumber	85.96	70.97	94.41	72.25
Cost per board foot (or square foot)	0.0945	0.1059	0.1037	0.1078
Cost per M square feet	94.50	105.90	103.70	107.80

[1]Resale of 76 percent of 3C boards at 4C prices; 92 percent of 4C boards at 5C prices.

[2]Repair of 67 percent of 3C boards; 59 percent of 4C boards.

[3]Resale of 9 percent of 3C boards at 4C prices; 33 percent of 4C boards at 5C prices.

II. OVERLAY PLANT OPERATING CONDITION ASSUMPTIONS

Production costs depend in part on the production situation and the specific product. In calculating average production costs from pilot plant data, assumed operating conditions and product specifications must consequently be identified and described.

ASSUMPTIONS

1. Operating schedules.
   A. One shift per day (400 operating minutes), 5 days per week, 250 days per year.
   B. Two shifts per day (800 operating minutes), 5 days per week, 250 days per year.

2. Production levels.

	Capability of-- Single shift	Capability of-- Double shift
Lumber overlay:		
Lineal feet/day	40 M	80 M
Lineal feet/year	10MM	20MM
Lumber repair:		
Square feet/day	40 M	80 M
Square feet/year	10MM	20MM

3. Products (for cost analysis).

   4/4 nominal 1- by 8-inch and 4/4 nominal 1- by 12-inch: Overlaid one face and wrapped two edges

   All products trimmed to nearest 1-foot length.

4. Overlays.

   5-mil vulcanized fiber:

   10-inch width for 1- by 8-inch product.
   14-inch width for 1- by 12-inch product.

5. Adhesive.

   Cross-linking polyvinyl acetate.

6. Cost schedules.

   Equipment investment and depreciation, labor, facility, and power costs are calculated and prorated over assumed levels of production (see appendixes III, IV, V, and VI).

III. FACILITY COST SCHEDULE

Type of operation	Minimal space requirements	Monthly costs[1]	Chargeable costs for-- Single shift	Chargeable costs for-- Double shift
	Sq. ft.		(Per M lineal feet)	
Overlay	4,800	4,800x$0.06 = $288	$288/840M = $0.34	$288/1,680M = $0.17
			(Per M square feet)	
Repair (chemical)	9,600	9,600x$0.06 = $576	$576/840M = $0.68	$576/1,680M = $0.34

[1]Based on $0.06 square foot; includes utilities other than electrical.

IV. INVESTMENT AND DEPRECIATION SCHEDULE

Amortization period (N) = 5 years. Residual value (R) = 0

Equipment	Initial cost I	Average fixed investment ((I-R)(N+1)/2N)+R	Annual depreciation charge, straight line (I-R)/N
OVERLAY EQUIPMENT:			
Laminator and associated equipment	$50,000	$30,000	$10,000
Auxiliary plant equipment	15,000	9,000	3,000
Total	65,000	39,000	13,000
REPAIR EQUIPMENT:			
Chemical repair--			
Loader-unloader	10,000	6,000	2,000
Scanner	18,000	10,800	3,600
Router	15,000	9,000	3,000
Dispenser	10,000	6,000	2,000
Restraint unit	40,000	24,000	8,000
Abrasive planer	18,000	10,800	3,600
Transfer units (3)	12,000	7,200	2,400
Auxiliary equipment	37,000	22,200	7,400
Total	160,000	96,000	32,000
Wood plug repair--[1]			
Double-head plugger[2]	20,000	12,000	4,000

[1]Assumptions are that plugging operation can be accommodated by existing plant lumber handling and conveying equipment.

[2]Not suitable for repairing lumber lower than 2 Common in quality; therefore, of limited value to a repair-overlay operation.

CHARGEABLE INVESTMENT AND DEPRECIATION COSTS

Type of operation	Annual costs			Operation costs for--	
	Depreciation	Interest[1]	Total	Single shift	Double shift
				(Per M lineal feet)	
Overlay	$13,000	$2,340	$15,340	$15,340/10,000M = $1.53	$15,340/20,000M = $0.77
Repair:				(Per M square feet)	
Chemical	32,000	5,760	37,760	$37,760/10,000M = $3.78	$37,760/20,000M = $1.89
Wood plug[2]	4,000	720	4,720	$4,720/325M = $14.52	$4,720/650M = $7.26

[1]Based on average fixed investment at 6 percent.

[2]Based on estimated repair capacity of 2,000 lineal feet of 1- by 8-inch stock per shift, or 325,000 square feet per year per plugging machine.

V. LABOR COST SCHEDULE

Position	Hourly rate[1]	Labor used per operating shift, and cost					
		Overlay[2]		Repair			
				Chemical		Wood plug	
		No.	Cost	No.	Cost	No.	Cost
Supervisor (lamination and repair)	$7.00	½	$3.50	½	$3.50	--	--
Skilled labor (laminator operator, repair crew foreman)	4.56	1	4.56	1	4.56	--	--
Semiskilled labor (patcher operator)	3.00	--	--	--	--	1	$3.00
Unskilled labor (overlay, repair crews)	2.75	3	8.25	3	8.25	--	--
Total	--	4½	16.31	4½	16.31	1	3.00

[1]Includes 20 percent addition to basic wage rate, for administrative overhead costs and fringe-benefit programs.

[2]In addition, setup and cleanup will require one crew member, working one man-hour overtime before and after each single- or double-shift operating period.

VI. ELECTRICAL POWER COST SCHEDULE

(Estimated use and cost same for overlay and chemical repair operations)

Power use and costs	General	Single shift	Double shift
POWER USE:			
Calculated peak plant load	= 98 M watts = 98 KVA		
Assuming .80 power factor, true power use	= 78.4 KW		
Assuming peak power use, monthly use		78.4x168 = 13,171 KWH	78.4x336 = 26,342 KWH
POWER COSTS:			
Assuming laminator operation is added to an existing manufacturing facility, the cost of electrical power would be an 'add-on' cost at lowest commercial rate:			
Demand charge		78.4x$1.25 = $98.00	156.8x$1.25 = $196.00
Energy charge		13,171x$0.01 = $131.71	26,342x$0.01 = $263.42
Total costs			
Monthly		$229.71	$459.42
Per M lineal feet[1]		$229.71/840M = $0.27	$459.42/1,680M = $0.27

[1]Per M square feet for chemical repair operation.

VII. SUMMARY -- UNIT COSTS APPLICABLE TO LUMBER REPAIR AND OVERLAY

Type of operation and cost item	Substrate item (4/4) Select	Mill-run	Repaired	Cost per unit	Cost per unit for-- Single shift	Double shift
	Dollars/M square feet					
OVERLAY:						
1- by 8-inch product						
Grade 3 Common	$73	$124	$ 95			
Grade 4 Common	57	315	106			
1- by 12-inch product						
Grade 3 Common	84	151	104			
Grade 4 Common	63	390	108			
Overlay (5-mil vulcanized fiber)				$21.60/M sq. ft.		
Adhesive				0.45/pound		
Labor, operating				0.272/minute		
Labor, setup and cleanup				0.046/minute		
Electrical power				0.27/M lineal feet		
					(Per M lineal feet)	
Equipment investment and depreciation					$1.53	$0.77
Building and facilities					.34	.17
Taxes, insurance, maintenance (at 6 percent)					.39	.20
CHEMICAL REPAIR:						
Urethane foam				$0.001/sq. inch of defect		
Labor				3.26/M sq. ft.		
Electrical power				0.27/M sq. ft.		
Miscellaneous supplies				1.00/M sq. ft.		
					(Per M square feet)	
Equipment investment and depreciation					$3.78	$1.89
Building and facilities					.68	.34
Taxes, insurance, maintenance (at 6 percent)					.96	.48

Mueller, Lincoln A., Roland L. Barger, Arthur Bourke, and Donald C. Markstrom.
1972. Roll laminating fiber overlays on low-grade ponderosa pine lumber. USDA For. Serv. Res. Pap. RM-97, 28 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Pilot plant tests were conducted with recently developed roll laminating equipment and thermosetting emulsion adhesives. Lumber that met substrate quality requirements was satisfactorily overlaid at speeds up to 180 feet per minute. Costs of overlaying, exclusive of substrate, ranged from \$0.04 to \$0.05 per square foot of product. A high proportion of Common grade lumber contains defects that cannot be overlaid. A second study phase found that abrasive planing (for surface defects) and urethane foam fillers (for voids) are promising repair techniques. Using selected or repaired lumber, overlaid products can be manufactured within a competitive price range. There is no strong market acceptance for such products at present, however, and aggressive market development will be needed. Commercial feasibility is currently restricted by the need for an effective automated defect repair system, and by lack of assured markets.

Keywords: *Pinus ponderosa,* forest products, lumber finishing.

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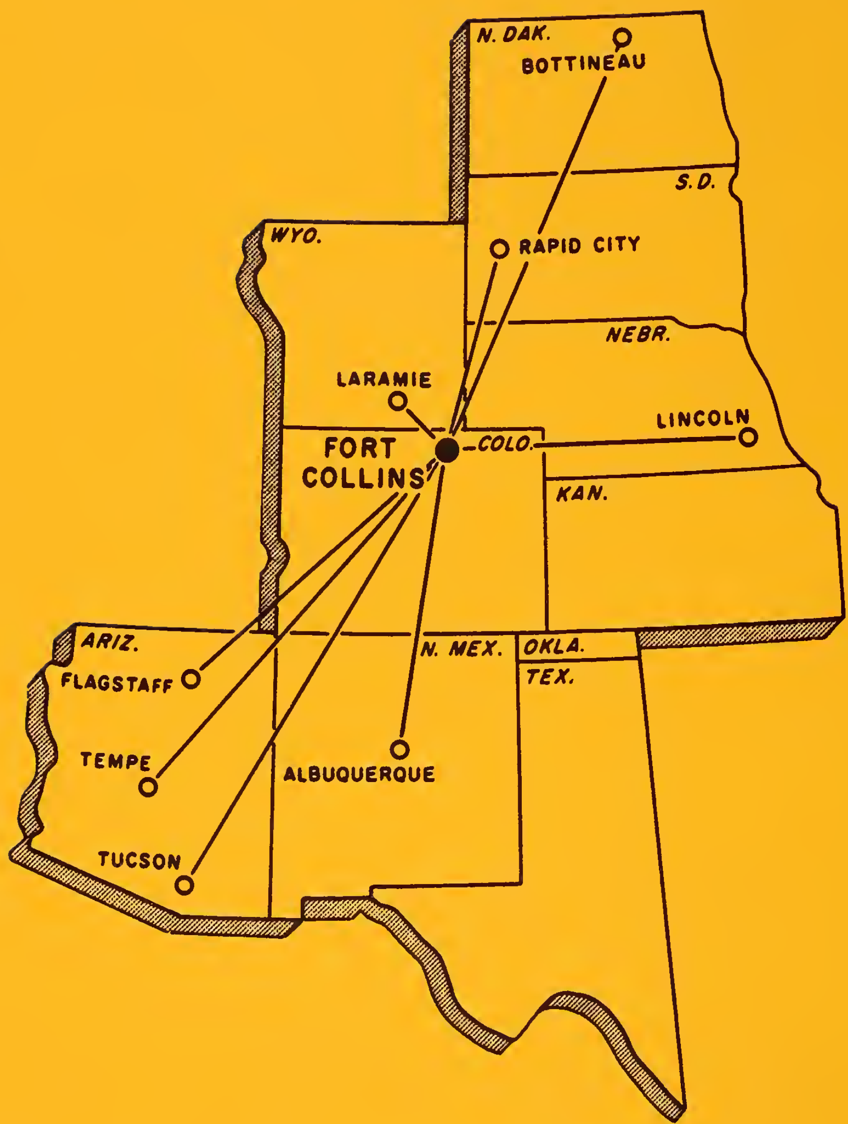
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